Fisheries Development in the Gulf FI:DP/RAB/80/015/3
Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates

PRELIMINARY STOCK ASSESSMENT FOR THE ABALONE TAKEN OFF THE SOUTH EAST COAST OF OMAN

- March 24 to April 2 1982

by

Michael J. Sanders
FAO Senior Fishery Biologist

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
UNITED NATIONS DEVELOPMENT PROGRAMME
Rome, 1982

SUMMARY

This paper describes a preliminary stock assessment for an unknown species of abalone (*Haliotis sp.*) inhabiting the south east coast of Oman. The resource supports a seasonal fishery, from September through April, involves divers using masks, rarely snorkels and fins, and never 'artificial' air supply equipment, and provides annual catches in the order of 200 tonne in-shell weight.

The stock assessment is based on a limited field survey, from which an estimate of the total stock at the end of the 1981/82 season is 1804 thousand pieces. Annual fishing and natural mortality coefficients of about 1.0 and 0.6 respectively were determined, the former relating to the exploited part of the resource in depths of about 8 metres and less.

The length at age relationship is described from observation of the growth checks on the shells; the estimates for the von Bertalanffy parameters being $L_\alpha = 11.9$, $K = 0.75$ and $t_0 = -0.08$. The derived relationship between weight in grams and length in centimetres is $w = 54.8 \times 10^{-3}\ \ell^{3.38}$, where w refers to the in-shell weight, and $w = 29.9 \times 10^{-3}\ \ell^{3.28}$, where w refers to the edible flesh weight.

Yield per recruit analyses show that increased annual catches are likely to result from increases in the amount of fishing, and decreases in the length at which the abalone are first caught. Compared to the current gross value of the fishery, estimated at about US$ 1.3 million, the tentative estimate of its potential future value is suggested as not exceeding US$ 2 million.

The possible future use of 'artificial' air supply equipment by the divers is discussed, from which it is concluded, principally on the basis of social considerations, that such use should be discouraged. The introduction of a 'legal' constraint on the capture of small abalone, is also suggested as unjustified, particularly in view of the 'natural' protection already being afforded.

PREFACE

The Fisheries Development in the Gulf Project (RAB/80/015) has been a joint undertaking of the Governments of eight countries in the region, assisted by the United Nations Development Programme and the Food and Agriculture Organization of the United Nations. As part of the operation of the project, FAO assigned Michael J. Sanders, FAO Senior Fishery Biologist, to carry out the preliminary stock assessment for the abalone taken off the south east coast of Oman between 24 March and 2 April 1982. The author is presently assigned to the UNDP/OPEC funded FAO project RAB/81/002, from which he was seconded to undertake the study documentated in this report.

ACKNOWLEDGEMENTS

The assistance from staff of the Omani Ministry of Agriculture and Fisheries is gratefully acknowledged, particularly the help from Research Assistant, Mr. Ali Al Harasy. Appreciation is also extended to Mr. P. Hoon of the Zawawi Trading Company.

CONTENTS Page

INTRODUCTION 1
METHODS 2
RESULTS AND DISCUSSIONS 4
    Environment 4
    Growth in Length 5
    Growth in Weight 7
    Spawning Season 7
    Abundance 8
    Production 10
    Mortalities 12
    Yield per Recruit 16
    Recruitment 18
CONCLUDING COMMENTS 21
REFERENCES 25

FIGURES

Figure 1 Diagram of Oman with 'important' place locations 26
Figure 2 Diagram showing measurement of abalone maximum length 27
Figure 3 Diagram showing position of cross-sectional cut and cross section of gonad 28
Figure 4 Diagram showing measurement of lengths to 'check' marks 29
Figure 5 Plot of $\ell_{t+1} - \ell_t$ against ℓ_t for the 'aged' abalone 30
Figure 6 Plot of length frequency distribution of abalone collected during survey dives on 29 and 30 March 82 31
Figure 7 Plot of length frequency distribution for dissected males and females separately 32
Figure 8 Plot of length frequency distribution for abalone shells discarded by commercial divers 33

CONTENTS (Continued) Page

Figure 9 Diagram of yields (Numbers) per 'recruit' for a range of seasonal fishing mortality coefficients and lengths at first capture 34

Figure 10 Diagram of yields (edible flesh weight) per 'recruit' for a range of fishing mortality coefficients and lengths at first capture 35

TABLES

Table 1 Shell lengths at each 'check' mark for each abalone 36

Table 2 Estimated shell lengths for given ages 38

Table 3 Mean weights and mean lengths for abalone sampled on 30 March 1982 39

Table 4 Estimated total weights and edible flesh weights for given ages 40

Table 5 Summary of mean gonad 'surface' areas relevant to abalone sampled on 29 and 30 March 1982 41

Table 6 Numbers and lengths of abalone caught during each of the survey dives on 29 and 30 March 1982 42

Table 7 Estimated numbers surviving per 'recruit' on October 1, following the application of different fishing mortalities 44

APPENDIX 1

Worksheet 45

APPENDIX 2

Suggestions concerning a possible future biological research programme 47

INTRODUCTION

The fishery for abalone (*Haliotis sp.*) in Omani waters is reported to take place along the coastline from Ras Marbat to Ras Nuss, east of Salalah, with the principal sites of landing being the villages of Sadh, Marbat and Hudbin; see Figure 1. Its longevity appears unknown, however, present-day divers are able to recall relatives participating in the fishery, over at least the previous two generations.

The participants are almost exclusively full time fishermen, although, as the range of alternative work opportunities have expanded, an increasing proportion is said to have resorted to part time involvement.

The fishing season is limited to the months of September through April; this results principally from the rough sea conditions caused by the south-west monsoon during the remainder of the year. While abalone provide by far the bulk of the incomes, the fishermen also generally engage in other types of fishing during the off-season.

The fishing method is by diving, with the exception that a small quantity of the beginning of the season catch is obtained by women and children wading in the shallows. The abalone are prised from the rocks with the help of a hand held metal bar. Access to the diving locations is being increasingly assisted by the use of boats.

The use of diving aids is generally confined to face masks, with flippers and snorkels being used only rarely. The maximum working depth is believed to be in the order of seven to nine metres. No divers use 'artificial' air supply equipment.

There are no official catch statistics available for this fishery, however, various rough estimates have been made which suggest the annual catch is around 200 tonne in-shell weight. Almost all the catch is sun 'dried' and reported to be shipped to Dubai before being re-exported to the Orient. A very limited local market also exists.

The divers are paid on a per piece basis, with the reported prevailing price at the end of the 1981/82 season being one Rial (= US$ 2.86) for each four abalone, irrespective of size. As additional 'incentives' the buyers are also said to pay some incidental expenses, such as hair-cuts and minor food costs.

The fishery has been subjected to increasing scrutiny over recent years, with consideration now being focused on the possibility of increasing production through the introduction of 'modern' diving methods and the exploitation of presently unfished areas. These unfished grounds, which have yet to be surveyed are reported to exist in slightly deeper water along the coastline presently being exploited, as well as the east coast of Masirah Island, the Kuria muria Islands and possibly elsewhere.

METHODS

An important component of the study involved a limited field survey of the abalone resources in the most intensively fished area, adjacent to Sadh. This included diving, which was done by the author, using standard 'hookah' equipment, and operating as would a commercial diver. The dives took place at eighteen representative sites spaced between Ras Qinqari and Ras Musaira.

At each site, abalone were collected during a standard time period of about seven to eight minutes, with the commencement of each period starting from the first sighting of abalone. The mean water depth relevant to each period was noted.

After the completion of each dive, the maximum shell length of every abalone collected was measured by ruler to the nearest millimetre; see Figure 2. In respect to some of the dives, the abalone caught were dissected, and the sex of each were recorded; green coloured gonads were taken as indicative of females, and cream coloured gonads as indicating males.

An attempt was also made to assess the state of reproductive maturity of these dissected abalone, which included determining the surface area of the exposed gonad, following a cross-sectional cut at the most anterior point of its attachment to the other viscera; see Figure 3. Measurement of the cross-sectional diameters was made by hand held ruler.

Attempts at ascribing ages to the abalone caught, by noting the presence of growth 'checks' on the shells, was initially prevented by the presence of extensive fouling on the shells of all but the small individuals. It was later determined however, that the sun dried shells that had been previously discarded by the commercial divers, were able to be 'cleaned' by immersion for thirty minutes in ten percent hydrochloric acid. The check marks were able to be noted on the shells cleaned in this way, and Vernier calipers were used to determine the shell lengths to each mark; see figure 4.

An additional data collection activity related to determining the weight at length relationship. The intention had been to obtain this from observations on individual abalone, however, the available weighing scale was not sufficiently sensitive to allow this. As such the procedure used was to divide a sample into four groups according to size, and then to obtain both the mean individual weights and the mean shell lengths of the abalone for each group.

Data also was collected relevant to determining the length composition of catches made by the commercial divers. This activity was assisted by the divers' practice of accumulating the discarded shells over several months in large mounds on the beaches; the action taken was to measure the lengths of a representative sample of these shells.

As well as undertaking the field work mentioned above, the author examined the small amount of written material available, and held discussions with the relevant interested groups, such as government officials, divers, merchants and others.

RESULTS AND DISCUSSIONS

Environment

In the context of understanding some of the biological characteristics of the abalone, it is necessary to have some understanding of at least the seasonal changes in environmental conditions prevailing off the south-east coast of Oman. A summary of such information is given in Vidal-Junemann (1981), after reference to Wyrtki (1973).

According to these sources, the major factors affecting the environment are the south-west and north-east monsoons. During the period from approximately May to September, the south-west monsoon causes the surface waters to be replaced by colder, nutrient rich, oxygen poor waters. The wind pattern then changes, producing a regime of north-east winds from about November to March, and is associated with a much less strongly developed water circulation effect.

The period of lowest temperatures is August (18.8 - 21.2 ^{o}C), and can be attributed to the upwelling. Thereafter the sea temperatures increase rapidly to high levels in November (26.3 - 28.1 ^{o}C), under the influence of prevailing air temperatures. Sea temperatures then decline to moderate levels in February (23.9 ^{o}C), after which they rise again to high levels in May-June (25.0 - 27.0 ^{o}C).

In respect to abalone food supply, it is likely that this would be most abundant immediately following the upwelling, when the water temperatures rise from September to November. This presumption was supported during discussions with divers, who advised that the period was associated with a greatly increased abundance of algae. Divers also commented on the somewhat related phenomena of a greatly increased abundance of abalone at this time; said to be some three times more abundant at the beginning of the season than at the end.

The dramatic drop in water temperatures between June and August, coupled with the presence of oxygen poor water, has been suggested as a possible cause of environmental stress, such as may have been reflected in a reported mass mortality of fish in the Salalah area during June 1976; see Vidal-Junemann (1981). Such stress conditions would presumably also be reflected in the occurence of checks to the growth of abalone, and is discussed in this context in the next section.

Growth in Length

Some forty-two shells were examined for growth checks, after cleaning in the way described previously. Numerous check marks were noted,and **have been** interpreted with reference to known seasonal changes in environmental conditions, and assumed changes in reproductive maturity state.

Not all of the marks are equally prominent. Generally the first mark, which is moderately prominent, appears when the length of the shells are about five centimetres, followed by two less prominent marks, and then a very prominent mark at about nine centimetres. Thereafter less prominent and very prominent marks appear consecutively. The data describing the shell lengths at each mark for each abalone are given in Table 1.

The most prominent marks (r_1, r_4, r_6, r_8 and r_{10}) have been interpreted as forming in July, as a result of the sharp decline in water temperature and oxygen content; it is the mean lengths corresponding to these marks that have been used in the estimation of the length at age relationship.

The presumed occurence of sexual maturity, possibly also spawning, in October/November, discussed in a later section, is taken as causing the second mark (r_2). The third mark (r_3) is interpreted as being caused by the moderate water temperature decline in February; while the subsequent less prominent marks (r_5, r_7, and r_9) are interpreted as a 'confusion' of the checks resulting from the October/November spawning and the February water temperature decline.

On the basis of these interpretations, the parameters L_α , K and t_o were determined; after assuming that growth in length for abalone is according to the von Bertalanffy equation:

$$\ell_t = L_\alpha (1 - e^{-K\,(t - t_o)})$$

where ℓ_t is the length at time t, L_α is the theoretical length when the rate of growth is zero, K is the growth rate expressed as an instantaneous coefficient, and t_o is the theoretical age when length is zero.

The estimation procedure involved a linear regression analysis of $\ell_{t+1} - \ell_t$ against ℓ_t, with the slope giving $-(1-e^{-K})$ and the x intercept giving L_α ; see Gulland (1969). A plot showing this regression is given in Figure 5. The birth date for abalone was taken as November 1, while the t_o was obtained after inserting the estimated K and L_α values, and the mean length corresponding to the check mark r_4 (t = 1.708), into the von Bertalanffy equation.

The values obtained for the parameters are L_α = 11.9 cm, K = 0.75 and t_o = -0.08 years; while a sample of estimated lengths for given ages, relevant to the use of these parameters in the equation, are given in Table 2.

Some confirmation of this length at age relationship has been noted from an examination of the length frequency distribution for the abalone taken during the field survey component of the study; see Figure 6. The most obvious mode in this plot is for the length class 10.0 to 10.4 cm, which is exactly the estimated length expected from applying the von Bertalanffy relationship, relevant to the 2+ cohort at the end of March. The mode for the length class 8.0 to 8.4 cm is also exactly the estimated length expected, for the 1+ cohort.

Concerning the possible differences in growth between the sexes, this matter was examined by referring to the length compositions of those abalone from the field survey that had been dissected; separate plots for the males and females are given in Figure 7. These data show that the modal length groups, corresponding to the 1+ and 2+ cohorts previously discussed, as well as the range, and maximum and minimum lengths, are all essentially the same for the males as for the females; suggesting that the two sexes have the same or very similar growth in length.

Growth in Weight

Using the mean individual weights and mean lengths shown in Table 3, the values obtained for the constants in the power curve relationship $w = a\ell^b$ where w is the weight in grams and ℓ is the length in centimetres, were $a = 54.8 \times 10^{-3}$ and $b = 3.38$, in the case of abalone total weight; and $a = 29.9 \times 10^{-3}$ and $b = 3.28$, in respect to the 'edible flesh' weight. The proportion of total weight which is edible flesh was estimated to be about 43 percent.

Combining the relationship between weight and length, with the relationship between length and age presented in the previous section, it is possible to derive for abalone the relationship between weight and age; a sample of estimated weights for given ages are provided in Table 4.

Spawning Season

The data concerning the gonad 'surface' areas are summarised in Table 5. They show a trend in respect of the females but not the males, for the areas to increase with shell length. When tested by an analysis of variance (one way) the means were found not to be significantly different ($P < 0.01$); the overall mean 'surface' area is 2.71 square centimetre.

The usefulness of these data is very limited in the context of describing the seasonality of spawning, as they relate to a single small time period, rather than many time periods over a full year as is required. Notwithstanding this insufficiency, the author's view from visual examination of many gonads, was that they were in a non-spawning condition.

The seasonality of spawning is invariably related to seasonal changes in environmental conditions. Assuming that the time of spawning is associated with an abundant food supply, and rising water temperatures, and is followed by a period conducive to the survival of the early life stages, spawning during October and November would seem most likely

It is during these months, following the cessation of the south-west monsoon, when water temperatures are rising and the algal food supply is abundant. The only other period of rising water temperature is from February to June, however this is followed by stress conditions of much lower water temperatures and oxygen levels.

The identification of size and age of sexual maturity is also made difficult, again due to the surface areas being for only one short -time interval. The data do show however that obvious sex differentiation occurs in abalone as small as about five or six centimetre, or a little over a year old according to the derived length at age relationship. The author's view, as yet unsubstantiated, is that individuals generally first spawn as two year olds.

Abundance

As mentioned previously, eighteen 'standard' dives were undertaken between Ras Qinqari and Ras Musaira, half of these being to the south of Sadh, and half to the north. The numbers of abalone of each length caught during each of these dives are given in Table 6 . The total number taken during the dives was 409, while the mean catch per dive was 22.7 pieces; the mean catches per dive for the areas south and north of Sadh were found not to be significantly different ($P < 0.01$).

The total number taken represents the catch during some 135 (= 18 x 7.5) minutes of diving adjacent to the seabed. Converting this to abalone density required knowledge of a relationship between diving time and the area of the seabed 'covered'. A suitable relationship, obtained from a study of the south east Australian abalone fishery, is provided in Beinssen (1979). The equipment and diving methods used in that fishery are identical to those used by the author in this study, and the abalone were seen to occupy the same type of habitat, under ledges and along vertical rock faces.

According to the Australian study, abalone divers operating commercially with hookah equipment cover an area of 1196 m^2 per searching hour, with searching time being the difference between the total diving time and the time taken in handling the abalone. The handling time for abalone was estimated as 5.1 seconds per individual.

Assuming that the author was equally proficient as a diver,which is reasonable in view of his experience in the Australian fishery, it is possible to relate these observations to the present study. The area of the seabed covered during the 135 minutes of diving was estimated to be 1998 m^2 (= 1196 (135/60 - 409 x 5.1/3600); in turn the estimate of the mean density of abalone at these locations is 0.205/m^2 (= 409/1998).

Utilising this density for estimating the abalone abundance requires a knowledge of the area of abalone producing reef. For this purpose reference has been made to the Admiralty chart 3785 ' Marbat to Masira Island' to obtain firstly the coastline lengths. A curvimeter was used, and the coastline length between Ras Qinqari and Ras Musaira found to be about 44 km. This entire coastline, with negligible exceptions, was judged to constitute abalone bearing reef. The width of this reef was not measured, but has been assumed to be 100 m, based on the 'visual' judgement of the author.

The tentative estimates of abalone abundance based on the observations presented above, are thus 902 thousand (= 44 x 10^5 x 0.205) pieces. This estimate refers to the number of abalone 'available' to a diver, and not to the total number present, as there is a considerable pre-recruit component of the populattion; these being un-available because of their secretive habit.

Concerning the coastlines from Ras Marbat to Ras Qinqari and Ras Musaira to Ras Nuss, it is claimed by the divers that they contain lower densities of abalone compared to the coastline adjacent to Sadh. This appears to be particularly so along the first mentioned coastline, where the daily catches at the beginning of the season by the best divers is claimed to be about 200 pieces, or some two-thirds that obtained by the divers near Sadh.

The length of these coastlines, measured by curvimeter, is about 86 km, a little less than double that between Ras Qinqari and Ras Musaira. As a 'first' estimate, it is tempting to conclude that the abundance in the unsurveyed area is about the same as in the surveyed area, and hence, that the abundance in the total fished area is about 1804 thousand pieces.

A previous survey of the grounds, undertaken in April/May 1981, reported in Development Applications Corporation (1981), produced an abundance estimate of some 1200 thousand pieces. The survey took place along the coastline from Ras Qinqari to Ras Hasik and involved the conduct of sixteen separate dives; the divers were equipped with hookah equipment. The greatest numbers of abalone were located adjacent to Sadh, with none being found north or adjacent to Ras Hasik.

Production

In the absence of a statistics collection system, tentative estimates of the annual production have been obtained from discussions with merchants and divers associated with the fishery. It was felt that they would have a reasonable idea of the numbers being landed, particularly as they trade on a per piece basis.

At Sadh, the principal landing site, the merchants advised that the daily catches at the beginning of the fishing season are in the order of 10 thousand pieces, and that this declines to some 3 thousand pieces by the end of the season. Partial confirmation of this was provided by independent advice from the divers, to the effect that the daily catches by the best divers generally declines from about 300 pieces to about 100 pieces during the course of the season.

In respect to the number of diving days, it was claimed that diving was possible and did take place on most days during the season. Keeping in mind that Fridays are generally observed as rest days, plus the existence of other religious holidays, the number of diving days was rather arbitarily taken as twenty per month.

The 'simple' estimate of the seasonal landings at Sadh is therefore 1040 thousand pieces (= 20 x 8 x (10 000 + 3000)/2). Converting this number to weight, on the basis that the mean weights per piece are 122 gm total weight and 53 edible flesh weight, both estimated from a knowledge of the mean length of the discarded shells which were sampled, gives the seasonal landings as 127 tonne total weight and 55 tonne edible flesh weight.

In respect to the other two landing sites of Marbat and Hudbin, the information available is less precise. The daily landings at the beginning of the season are claimed to be 3 thousand and 4 thousand respectively at these sites and hence assuming the same twenty diving days per month, and the same approximately two-third seasonal decline in daily catches, provides 744 thousand pieces (= 20 x 8 x (7000 + 2300)/2) as the estimated seasonal catch in numbers. Using the same conversion to weight gives the seasonal catch in total weight as 91 tonne or 39 tonne of edible flesh.

Combining the estimates for the three landing sites, gives a seasonal catch of 1790 thousand pieces for the fishery, equivalent to some 218 tonne total weight or 94 tonne of edible flesh weight.

These values are somewhat higher than those given by Development Applications Corporation (1981), which are 1200 thousand pieces or between 136 and 181 tonne total weight; no account of the basis for these estimates is given. By contrast, estimates contained in an internal report prepared by a Director of the Omani Ministry of Fisheries and Agriculture were higher, 3840 thousand pieces, equivalent to 480 tonne total weight; and are based on 200 divers, each collecting 80 pieces per day, for 30 days per month over 8 months.

Mortalities

The general observation by the divers operating from Sadh, that the abundance of abalone in the exploited areas at the beginning of the season is some three times that at the end of the season, is useful in respect to determining an initial estimate for the total mortality. The 'simple' conclusion from this observation is that two thirds of the abalone present at the beginning of the season die during the ensuing eight months; probably more than this number dies if one considers some recruitment taking place during the season.

It is more convenient to consider this mortality as an exponential coefficient, and for the purpose to assume that changes in the population numbers can be represented by the equation $N_2 = N_1 e^{-zt}$ where N_1 and N_2 are the numbers present at the beginning and end of a time period t, z is the total mortality coefficient, equal to F + M where F and M are the fishing and natural martality coefficients, and e is the exponential coefficient.

The resulting estimate for the total mortality coefficient, relevant to the above observation is 1.10 ($= -\ell n\ 1/3$) which will be an under-estimate if recruitment occurs during the fishing season.

Another method for estimating total mortalities relates to the use of the mean lengths of individuals in the catches. The underlying concept is that as the level of mortality increases, the mean length of individuals in the population decreases. A commonly used equation describing this concept is $Z = K (L_\infty - \bar{\ell})/(\bar{\ell} - \ell c)$, where Z, K and L_∞ are as previously defined, $\bar{\ell}$ is the mean length of individuals in the catch, and ℓc is the mean length at entry into the fishery, see Gulland (1969).

The two sources of data available for use with this equation are the lengths of the shells discarded by the commercial divers, and the lengths of the abalone taken during the survey dives; the mean length at entry into the fishery has been assumed to be 8.5 cm in respect to both sources, which seems reasonable on the basis of a visual examination of the length frequency distributions; see Figures 6 and 8.

The mean length for the discarded shells is 9.7 cm, from which an estimate for the total mortality coefficient is 1.37 ($= 0.75 (11.9 - 9.7)/(9.7 - 8.5)$). In contrast to the earlier estimate, this value relates to the mortality during the full year, and not just the fishing season; while like the previous estimate, it refers to the exploited component of the population.

The abalone collected during the survey dives were taken from depths ranging between six to twelve metres; that is from within and outside the grounds subjected to exploitation by the commercial divers. As such, separate mean lengths were determined, for the individuals taken from depths less than eight metres, and for those from greater depths; the former is presumed to relate to the exploited component of the resource, and the latter to the unexploited component.

The respective mean lengths obtained are 9.6 cm and 10.5 cm, from which the estimates of the total mortality coefficients are 1.57($= 0.75 (11.9-9.6)/(9.6-8.5)$)and 0.53 ($= 0.75(11.9-10.5)/(10.5-8.5)$).

These values relate to the mortalities occuring during the full year. Furthermore the latter value is an estimate of the natural mortality coefficient as it derives from data concerning the unexploited component of the resource. The difference between the two values, equal to 1.04, is an estimate of the fishing mortality coefficient applying to the exploited component of the resource.

A third method for estimating the total mortalities, which is not entirely independent from the above, in that the same data sources are used, is described in Jones (1981). The procedure involves arranging the length frequency data into length classes and estimating the cumulative catches in each length class. When the natural logarithms of the cumulative catches are plotted against the natural logarithms of the values of $(L_\alpha - L)$, where L is the lower length of each length class, a relationship is obtained which is linear over a considerable part of its range. The slope over this linear portion provides on estimate of Z/K.

The application of this method for the determination of the total mortality coefficient, requires prior estimation of both L_α and K. Furthermore these two parameters must be derived in respect to an age at length relationship, rather than a length at age relationship, and hence they will have different values than those presented earlier.

The procedure for estimation of the L_α was according to the relationship $L_\alpha = \ell m/0.95$, where ℓm is the maximum length found in the samples; and as the largest individual measured during the study was 14.2 cm, the estimated L_α is 14.9 cm. The estimate of K compatible with this L_α and the incremental growth reflected by the modes at 8.2cm and 10.1 cm in the length frequency distributions from the survey dives, is $0.33(= - \ell n\ (14.9 - 10.1)/(14.9 - 8.2))$.

Applying Jones' method to the length frequencies for the discarded shells gives an estimate for Z/K of4.99, from which the estimate for the total mortality coefficient is 1.65 (= 4.99 x 0.33). When applied to the abalone collected from depths less than eight metres during the survey dives,the estimates are 4.62 for Z/K and 1.52 (=4.62 x 0.33) for the total mortality coefficient; while the respective estimates in respect to the individuals collected from greater depths are 2.86 and 0.94 (=2.86 x 0.33). Each of the total mortality coefficients presented here relate to the full year.

Further comment concerning mortality estimates is possible with reference to the previously estimated abundances and seasonal catches. For the coastline between Ras Qinqari and Ras Musaira, the previously estimated end of season abundance is 902 thousand pieces. Assuming that the abundance on both the exploited and unexploited grounds at the beginning of the season is some three times that at the end of the season, which is presumably an exaggeration, the abundance at the beginning of the season will be 2706 thousand abalone.

The difference between these beginning and end of season abundances, 1804 thousand, provides a measure of the mortality in the intervening period, assuming there is negligable within season recruitment; this number dying will include the quantity caught, estimated at 1040 thousand pieces; the remaining 764 thousand being those dying from natural causes.

Representing these seasonal mortalities as coefficients, gives an estimate for the total mortality coefficient at 1.10 (= $-\ell n$ 1/3 the fishing mortality coefficient as 0.63 (= 1.10 x 1040/1804) and the natural mortality coefficient as 0.47 (= 1.10 - 0.63).

These estimates, which relate to both the exploited and unexploited components of the resource,are known to be biassed. The underlying assumption that the abundance at the beginning of the season is three times that at the end of the season is certain to be an exaggeration;

tending to cause the total and natural mortality coefficients to be over-estimated, and the fishing mortality coefficient to be under-estimated.

A possible bias acting in the other direction, relates to the assumption that the within season recruitment is negligable. Some recruitment is certain to take place during the season, although it is felt that this is likely to be minor, when compared to the magnitude of the recruitment at the beginning of the season.

Yield per Recruit

The objective underlying the yield per recruit analyses, is to investigate the relative affects on yields of changing the level of exploitation and the size at which the exploited individuals are first liable to capture. The model chosen for the analyses is one which allows the life of the population to be considered during each of a number of small time intervals, with each interval able to be associated with different values for growth and mortality, as required.

The mathematical expression of the model is:

$$Y = \Sigma Fi/Zi\ Ni\ (1 - e^{-Zi\,\Delta t})\ Wi$$

where Y is the yield, Fi, Zi and Wi are the fishing mortality and total mortality coefficients and mean weight of the individual abalone, in the i^{th} period of durationΔt, and Ni is the number of abalone recruited at the beginning of the i^{th} period.

The model was applied with the number of 1+ cohort abalone recruiting into the fishery at September 1 in each year taken as 1000, the natural mortality coefficient equal to 0.6,and the individual weights of abalone in each time period being according to the edible flesh weight at age relationship presented earlier; the time intervals chosen were one month. Separate yields, both in terms of numbers and edible flesh weight, were estimated for a range of fishing mortality coefficients and lengths at first capture. A worksheet showing a sample set of calculations is given in Appendix 1.

Figures 9 and 10 show the yield (in numbers and edible flesh weight) per 'recruit' for the range of fishing mortality coefficients from 0.5 to 2.5, and a range of lengths at first capture from about 9 cm to 11 cm. The prevailing seasonal fishing mortality coefficient is considered to be around 1.5, at least in the Ras Qinqari to Ras Musaira area fished by the divers from Sadh, and the prevailing length at first capture is thought to be about nine centimetres.

It appears from an examination of Figures 8 and 9 that increasing the level of fishing mortality over the range presented would result in increased yields. As an example, the model predicts that from increasing the seasonal fishing mortality coefficient by 33 percent to 2.0, there would be an about ten percent increase in the numbers of abalone caught annually, or about a six percent increase in edible flesh weight, at the prevailing length at first capture of about nine centimetres.

A more extreme example, not depicted in the Figures, involves using a coefficient of 7.5 or some five times higher than the prevailing level, and the about nine centimetre length at first capture . In this case, the predicted increases in numbers and edible flesh weight caught annually would be a little above thirty percent and about fourteen percent respectively. It is important to note however that in this example, the fishery would be based almost entirely on the late 1+ and early 2+ cohorts with very few surviving to the next season. Furthermore the within season declines in catch rates would also be extreme in that during the first four months of the season, daily catches would decline by about ninety percent.

Conceptually, yields could also be increased by lowering the size at which the abalone are first liable to capture, however, in a practical sense such a result may not be possible, or desirable.

According to the length frequency distributions in the catches, discussed earlier, it appears unlikely that greatly increased numbers of smaller abalone could be taken because of their generally secretive habit, as well as the 'protection' afforded by rough sea conditions occuring during the closed season.

The application of the yield per recruit model as discussed above, relates solely to the exploited component of the population. Any future exploitation of the abalone in waters deeper than can presently be reached by the divers, would almost certainly also result in increased yields. The only possibility of this not being so, would occur if there was extensive migration of the abalone across depth zones. The fact that greatly different total mortality coefficients were estimated for the population in depths less than eight metres, compared to greater depths, suggests that such migration is negligible.

The magnitude of the additional yield likely to result from exploiting the abalone in the deeper waters is unknown, however, it is felt that the additional yield would be modest. This view results mainly from the authors underwater observations, from which it appeared that the coastal reefs generally merge into sand at about ten metres depth, with the lower part of the reef appearing to provide relatively poor habitat for abalone. The one exception was to find abalone present in 12.5 metres depth during one dive.

During the previous survey, by Development Applications Corporation (1981), abalone were found to a depth of 20 metres on one dive and to 15 metres on two dives; for most of the other thirteen dives the abalone were located in less than 10 metres. Additional information based on survey dives in these deeper waters is required.

Recruitment

One deficiency of the model used in the previous section is that in assuming constant recruitment, it ignores the possibility of recruitment being impaired as a result of very high fishing mortality levels. Such impairment could occur if the fishing mortality becomes so high, that insufficient parent stock are able to survive in order that the level of reproductive success and subsequent recruitment can be maintainted at satisfactory levels.

It is possible in part, with reference to the results from yield per recruit analyses, to show how this may occur. Taking the example in Appendix 1, it is possible to know the numbers of survivors from the given recruitment on any chosen date; on October 1 the numbers are 839 (1+ cohort), 170 (2+ cohort), 34 (3+ cohort), 7 (4+ cohort) and 1 (5+ cohort), giving a total of 1051. Examination of Table 7 allows a comparison of these values, with those resulting from the application of different mortality coefficients within the same yield per recruit model.

This Table shows clearly that increased fishing mortalities are associated with decreased numbers of future parent stock, as well as decreases in their mean ages. In the extreme case of applying a fishing mortality coefficient of 7.5, the parent stock consists almost entirely of the late 1+ cohort, with the consequence that each parent will only spawn once before death. In addition, the estimated number of parents is only a third of that present under the application of a fishing mortality coefficient of 0.5.

Whether such effects on the parent stock would lead to consequential impairment of the future recruitment of abalone are unknown, however, until this matter is clarified, any consideration towards substantially increasing the fishing mortality should be approached with caution.

Some comment about the magnitude of the current annual recruitment is possible, with reference to the previously mentioned end of season abundance of 902 thousand pieces, for the Ras Qinqari to Ras Musaira coastline. Applying a natural mortality coefficient equal to 0.6, leads to an estimated 703 (= 902 $e^{-0.6 \times 0.416}$) thousand surviving to the beginning of the next season. Assuming the abundance at the beginning of the next season is 2706 thousand, three times that for the end of the season, which is known to be an exaggeration, leads to an over-estimated 2003 (= 2706 - 703) thousand recruits by the beginning of the season.

An alternative estimate for the annual recruitment, this time applying to the exploited area only, can be obtained with reference to the relationship:

$$R = C\ (F + M)/F$$

where R and C are the numbers recruited and caught respectively, and the other symbols are as previously described; see Gulland (1969). The resulting estimate is 1664 (= 1040 (1.0 + 0.6)/1.0) thousand, when the annual fishing and natural mortality coefficients are taken as 1.0 and 0.6 respectively.

In respect to identifying the ages of the recruits, it would appear from both a knowledge of the length at age relationship, and the length composition for the available part of the population, that the individuals from the 0+ cohort only rarely occur in the catches, while individuals from the 1+ cohort only begin to recruit substantially as they approach the age of two years. As the commercial divers tend to remove all the abalone visible to them, as did the author during the survey dives, the general scarcity of the 0+ and early 1+ cohorts in the catches presumably results from their secretive habit.

CONCLUDING COMMENTS

In a previous section, it was suggested that yields from the existing fishery might be increased as a result of increasing the fishing mortality coefficient, which in turn is directly proportional to the magnitude of the fishing effort. In monetary terms, the fisheries present gross value, believed to be about US$ 1.3(= 1.790 x 2.86/4) million could possibly be increased up to about US$ 1.7 (= 1.3 x 1.3) million, by encouraging more fishing effort on the presently exploited portion of the resource.

Less than this amount would be realised however, if the increased fishing effort were associated with reductions in the level of recruitment; extremely high fishing effort might even result in less yield and hence lower revenues than at present, and certainly would result in less yield per effort. While it is not known whether such a relationship does exist, its possibility must be acknowledged.

Exploitation of the abalone in the adjacent waters presently too deep to be reached by the divers, would also result in some additional yield and gross revenue. The magnitude of this potential is as yet unknown, but likely to be modest in the authors view.

As a tentative assessment, the future gross value of the fishery from increased exploitation of both the exploited and presently unexploited components of the resource, is not likely to exceed US$ 2 million.

Presuming an attempt were made to realise this potential, the only practical means would be through the introduction of modern diving technology; including equipment which permits the divers to remain continuously under-water and to reach greater depths. Such equipment would allow the individual divers to greatly increase their fishing power; perhaps as much as ten times, on the basis of the authors experience.

Those responsible for managing the fishery would need to recognise however that any future introduction of modern diving technology would not be without problems. For example, equipping all the several hundred divers presently engaged in the fishery, would probably result in excessive fishing effort, with decreased yields and gross revenues. Complimentary controls such as shortening the fishing season would overcome this problem, but probably introduce others; for example the need for such controls to be associated with the employment and equipping of enforcement staff.

In practice it would not be possible to equip all the present divers, as some, perhaps many, would not be capable or willing, for medical, psychological or other reasons, to embrace the new technology. Those that were equipped would need to be carefully trained, to ensure the avoidance of medical problems and possible fatalities.

Allowing some, but not all divers to become equipped, would need to be associated with some determination of what constitutes the 'right' number of'privileged' divers, and procedures for deciding which divers are to be equipped, and how retiring divers are to be replaced. This level of management sophistication is unlikely to be considered justified, in view of the modest benefits being sought, and the traditional nature of the present fishery and its participants.

The existence of two groups of divers, those using the modern equipment, and those without, could be expected to be associated with a high level of between group antagonism. As a direct consequence of the equipping of divers, the catch rates by the traditional divers would become less; unless the two groups were 'physically' separated, which in turn would present a difficult enforcement problem.

A greater source of antagonism could be expected to result from divers in the equipped group being able to earn very much more money than those from the other group. In the author's view, the extent of income disparity between divers from the two groups could be as much as ten times.

The consequences of such additional antagonisms might be extreme, when coupled with the alleged undercurrent of 'tribal' conflicts claimed still to exist within the community.

The possibility of other social 'costs' to the community also exists. Presently there are several thousand people, the divers and their families, situated in three villages, who are dependent principally on abalone for their livelihoods. If, as is conceivable, the potential catch was able to be taken by less than fifty equipped divers, a large proportion of the community would be faced with the possibly difficult task of finding alternative means of support.

Considering that the magnitude of the potential benefits from more fully exploiting the abalone resource are modest, and having in mind the likely associated problems, only some of which are mentioned above, it is the authors view that the existing character of the fishery should not be allowed to change; at least not until there has been substantial additional investigations, not only concerning the resource, but also the diving community; see Appendix 2.

As the divers and merchants are already aware of the usefulness and means of obtaining 'artificial' air supply equipment, and are likely to take some initiatives in this direction in the near future, unless prevented, some direct or indirect prohibition on the use of the equipment may be needed, if the character of the fishery is not to change.

So far this report has dealt exclusively with the existing fishery, and as mentioned earlier, there are other localities along the Omani coastline where abalone are believed to exist. The initial actions in respect to these areas would presumably include the conduct of planned surveys, and if the future exploitation of these resources seemed justified, to then determine the best ways for this to be encouraged.

In respect to the latter, it may not be possible or feasible to encourage adequate future exploitation without allowing the use of 'artificial' air supply equipment. This matter would need to be given careful consideration following the completion of the survey phase.

Returning to the existing fishery, and a consideration of the justification of introducing some minimum size control on the abalone being caught, it would seem that such action is not justified, at least at the present time. By virtue of the secretive habit of the 0+ and early 1+ cohorts, adequate protection of the immature abalone is already being provided. Also of relevance are the results of the yield per recruit analyses, which show that lowering the size at first capture would be associated with increased yields.

Furthermore, at the current level of exploitation, there would seem to be very adequate numbers of parent stock available, particularly at the important time early in the season, when spawning is assumed to take place. The existence of presently unexploited stocks in the slightly deeper waters provides added protection, in respect to maintaining satisfactory levels of recruitment. Should the exploitation of the abalone be greatly increased in the future however, the need for some control on the size of abalone taken may need to be reconsidered.

REFERENCES

Beinssen, K.H. 1979	Fishing Power of Divers in the Abalone Fishery, Victoria, Australia. International Council for the Exploration of the Sea. Special Meeting on Population Assessment of Shellfish Stocks (47). 9 p.
Development Application Corporation 1981	Report of the Abalone and Lobster Study in the Dhofar Region. Prepared with agreement between Waleed Associates and the Ministry of Agriculture and Fisheries. 33 p. (Mimeo)
Gulland, J.A. 1969	Manual of Methods for Fish Stock Assessment. Part 1. Fish Population Analysis. *FAO Man.Fish Sci.*, (4): 154 p.
Jones, R. 1981	The Use of Length Composition Data in Fish Stock Assessments (with Notes on VPA and Cohort Analysis). *FAO Fish.Circ*. (734): 59 p.
Vidal-Junemann, J. 1981	Yield Estimates for Fisheries Resources in the Sultanate of Oman. Regional Fishery Survey and Development Project. FI:DP/RAB/71/278/16. 80 p.
Wyrtki, K. 1973	Physical Oceanography of the Indian Ocean. In Biology of the Indian Ocean, edited by B. Zeitschel. *Ecol.Stud*., (3). 36 p.

FIGURE 1 Diagram of Oman with 'important' place locations

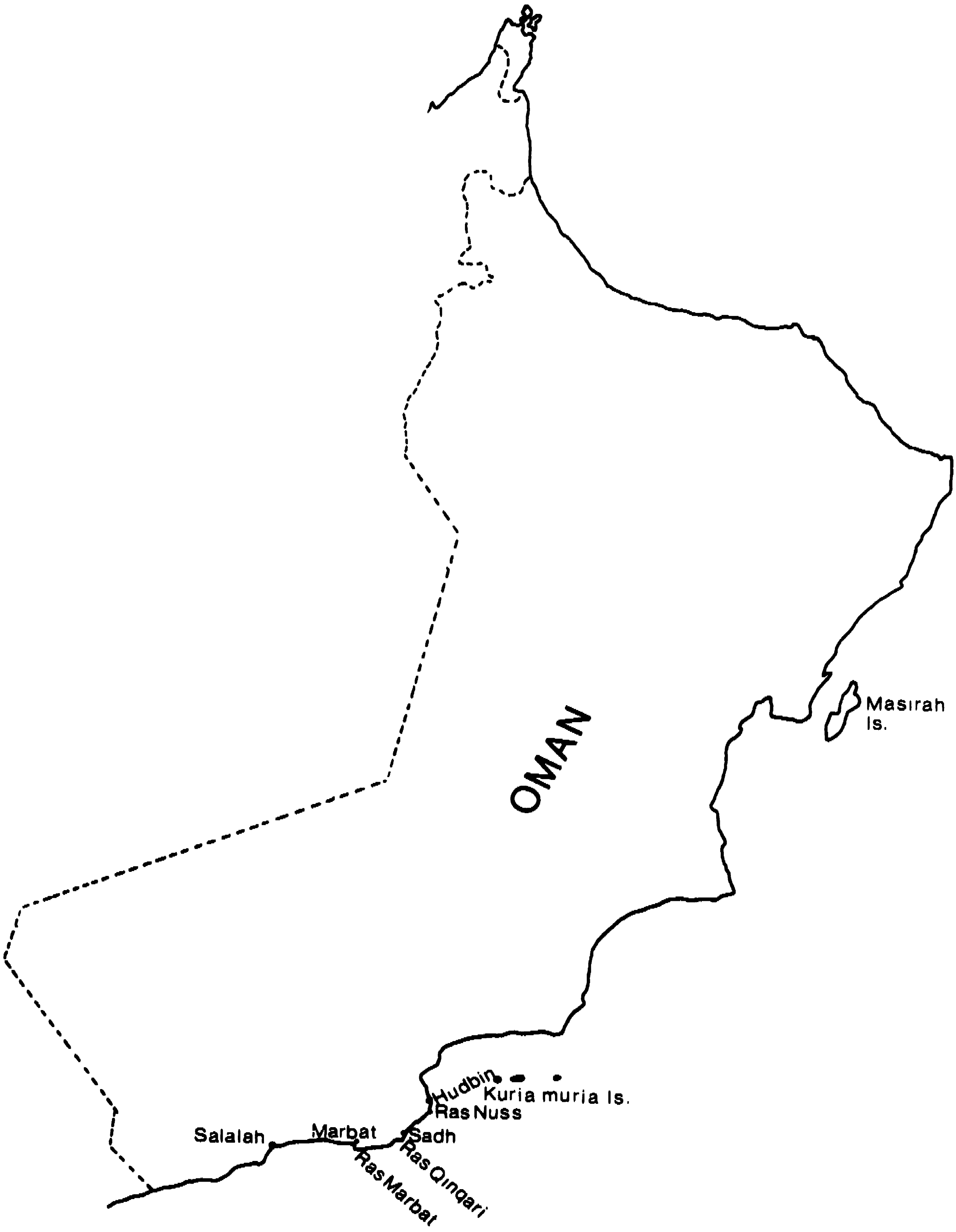


FIGURE 2 Diagram showing measurement of abalone maximum length

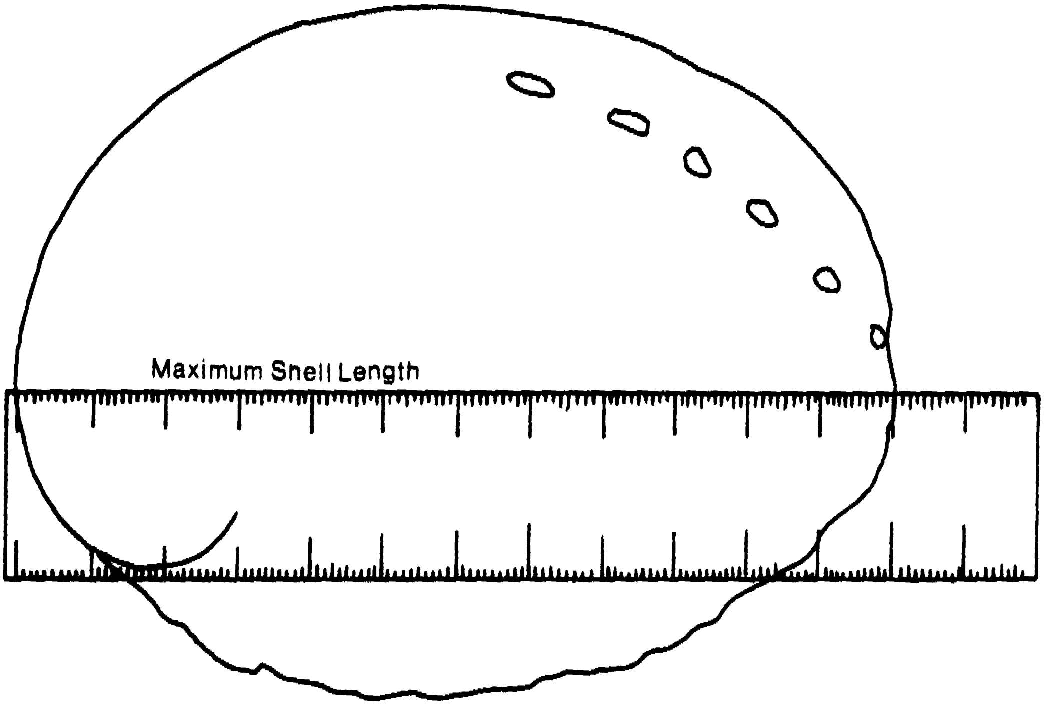
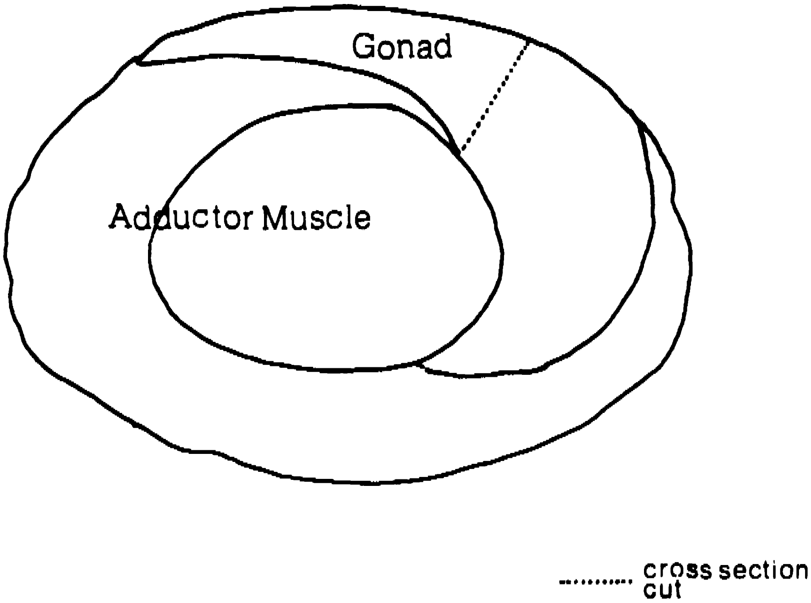


FIGURE 3 Diagram showing position of cross-sectional cut, and cross section of gonad.



Cross Section View

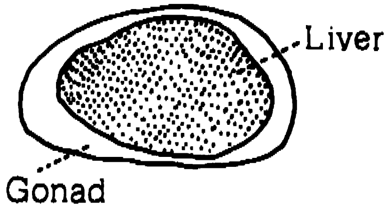


FIGURE 4 Diagram showing measurement of lengths to 'check' marks

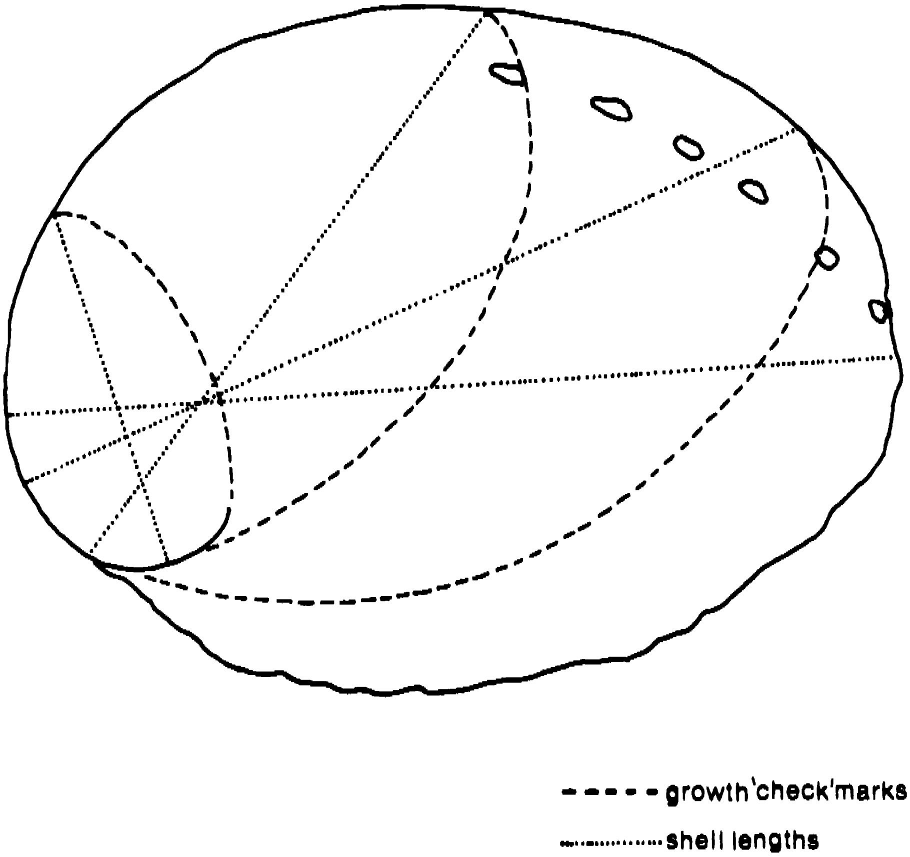


FIGURE 5 Plot of $\ell_{t+1} - \ell_t$ against ℓ_t for the 'aged' abalone

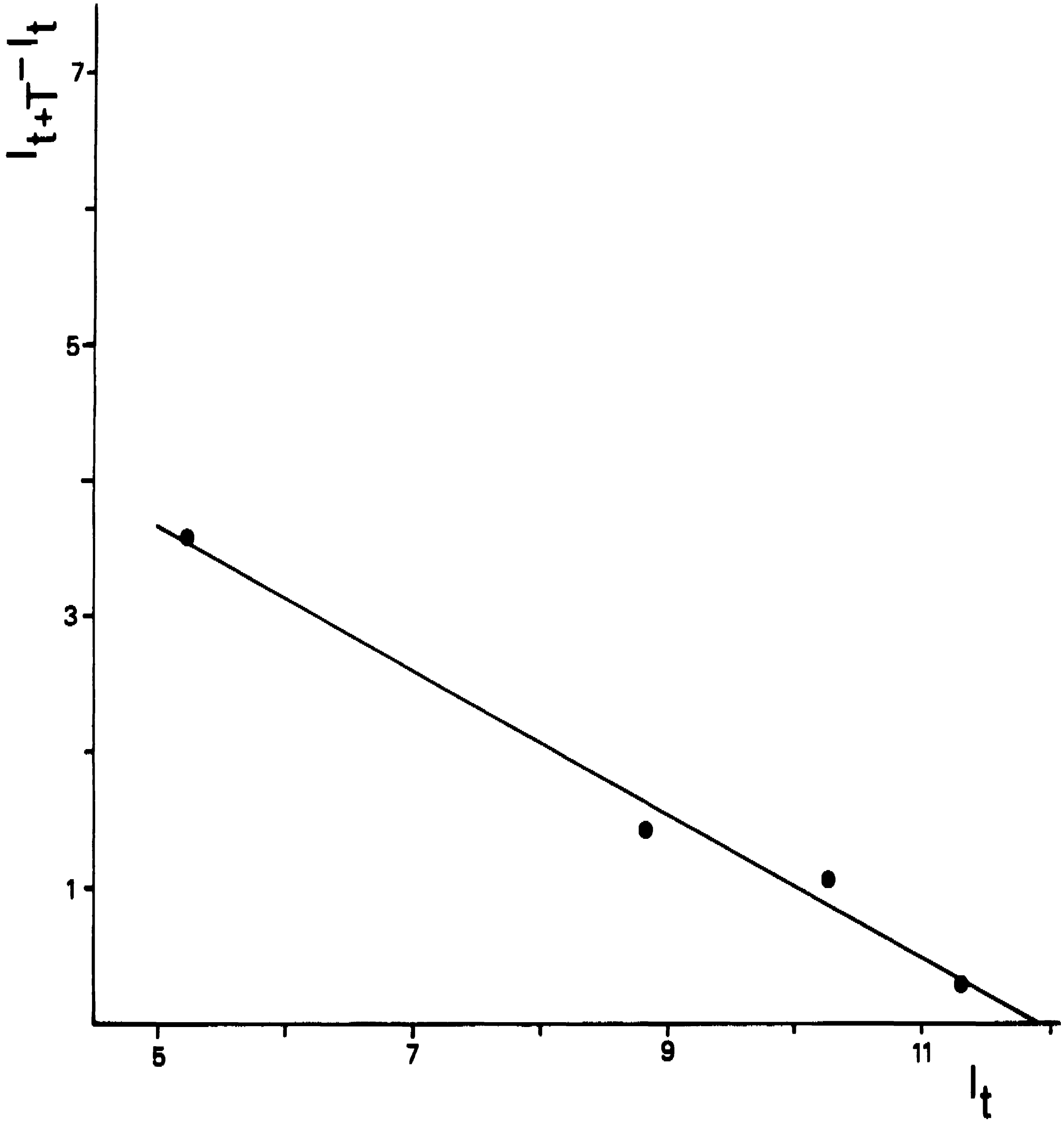


FIGURE 6 Plot of length frequency distribution of abalone collected during survey dives on 29 and 30 March 1982.

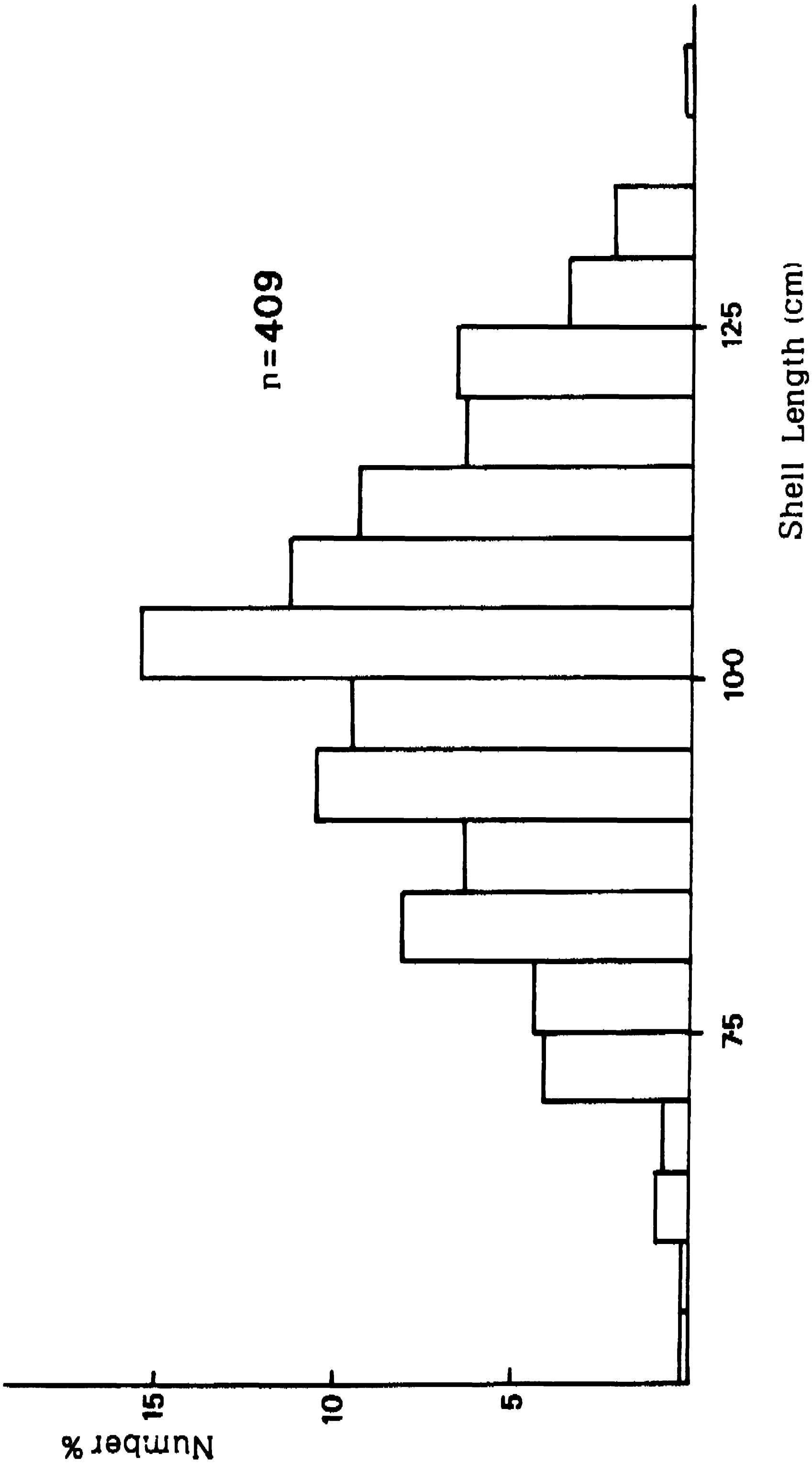


FIGURE 7 Plot of length frequency distributions for dissected males and females separately.

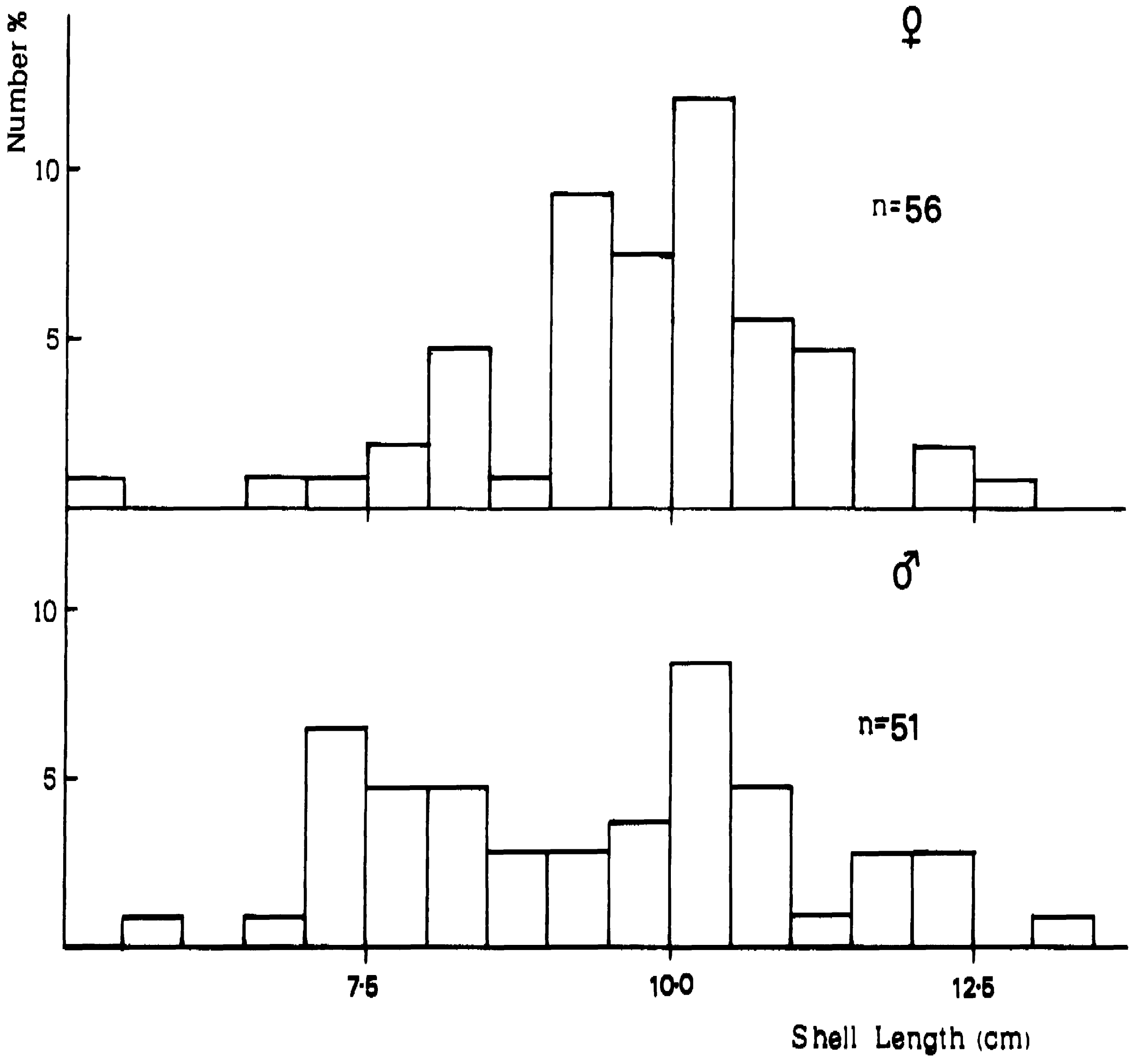


FIGURE 8 Plot of length frequency distribution for abalone shells discarded by commercial divers.

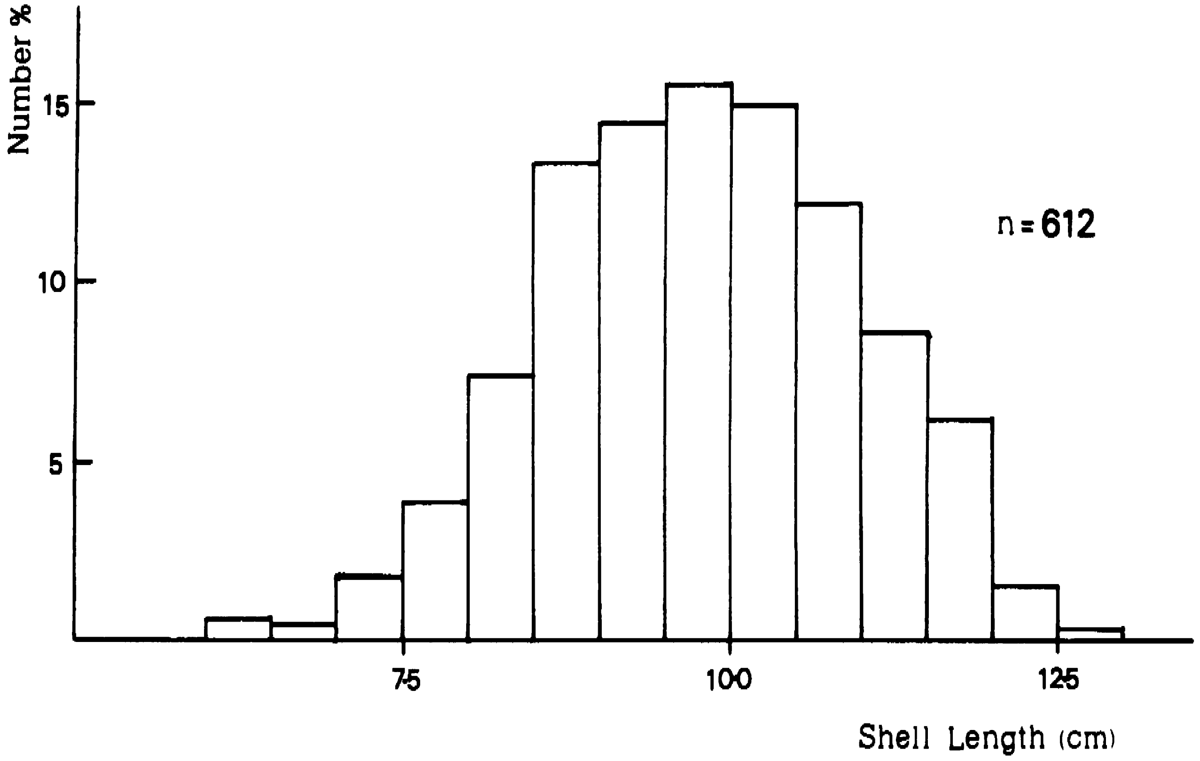


FIGURE 9 Diagram of yields (Numbers) per 'recruit' for a range of seasonal fishing mortality coefficients and lengths at first capture.

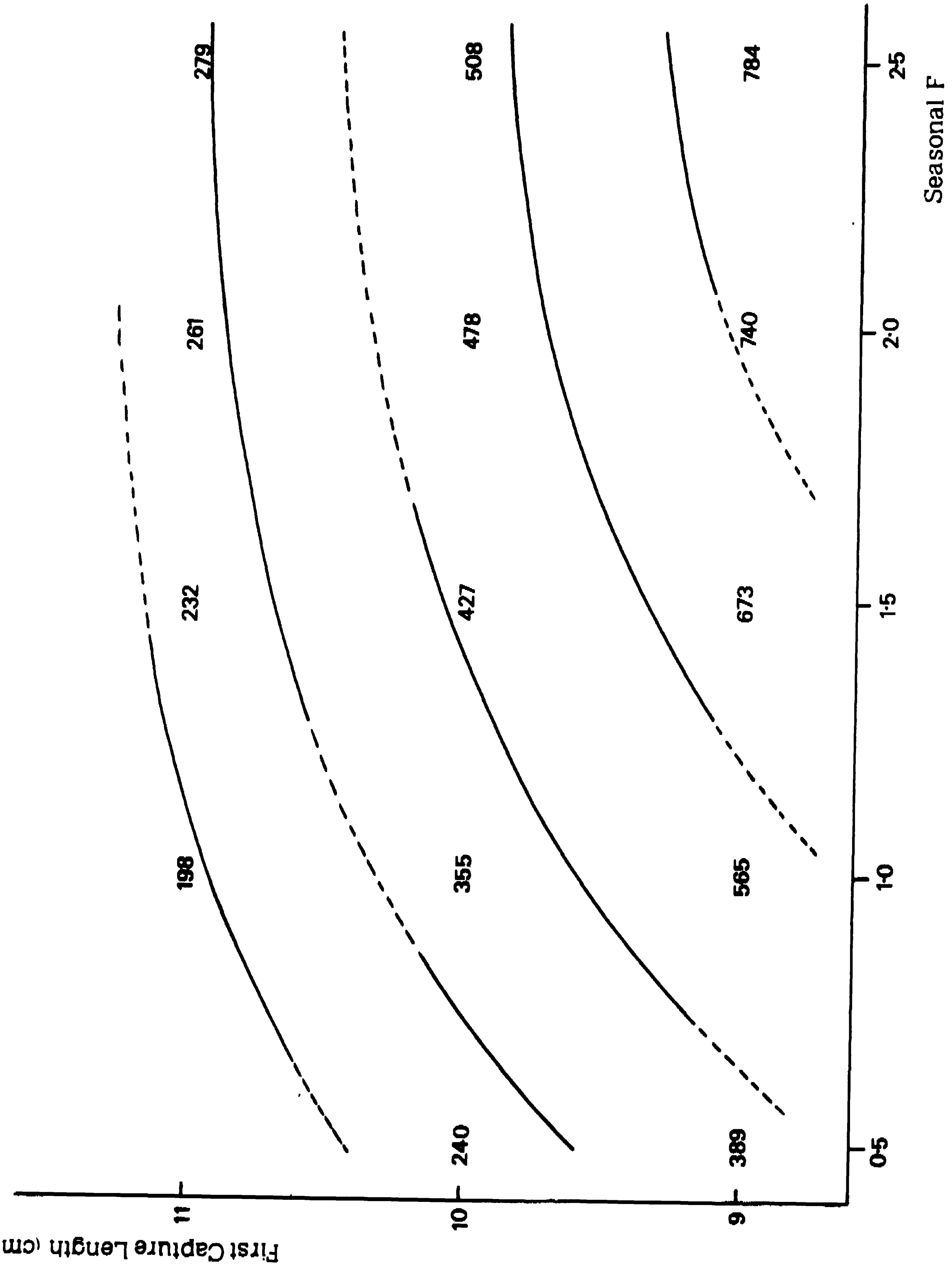


FIGURE 10 Diagram of yields (edible flesh weight) per 'recruit' for a range of fishing mortality coefficients and lengths at first capture.

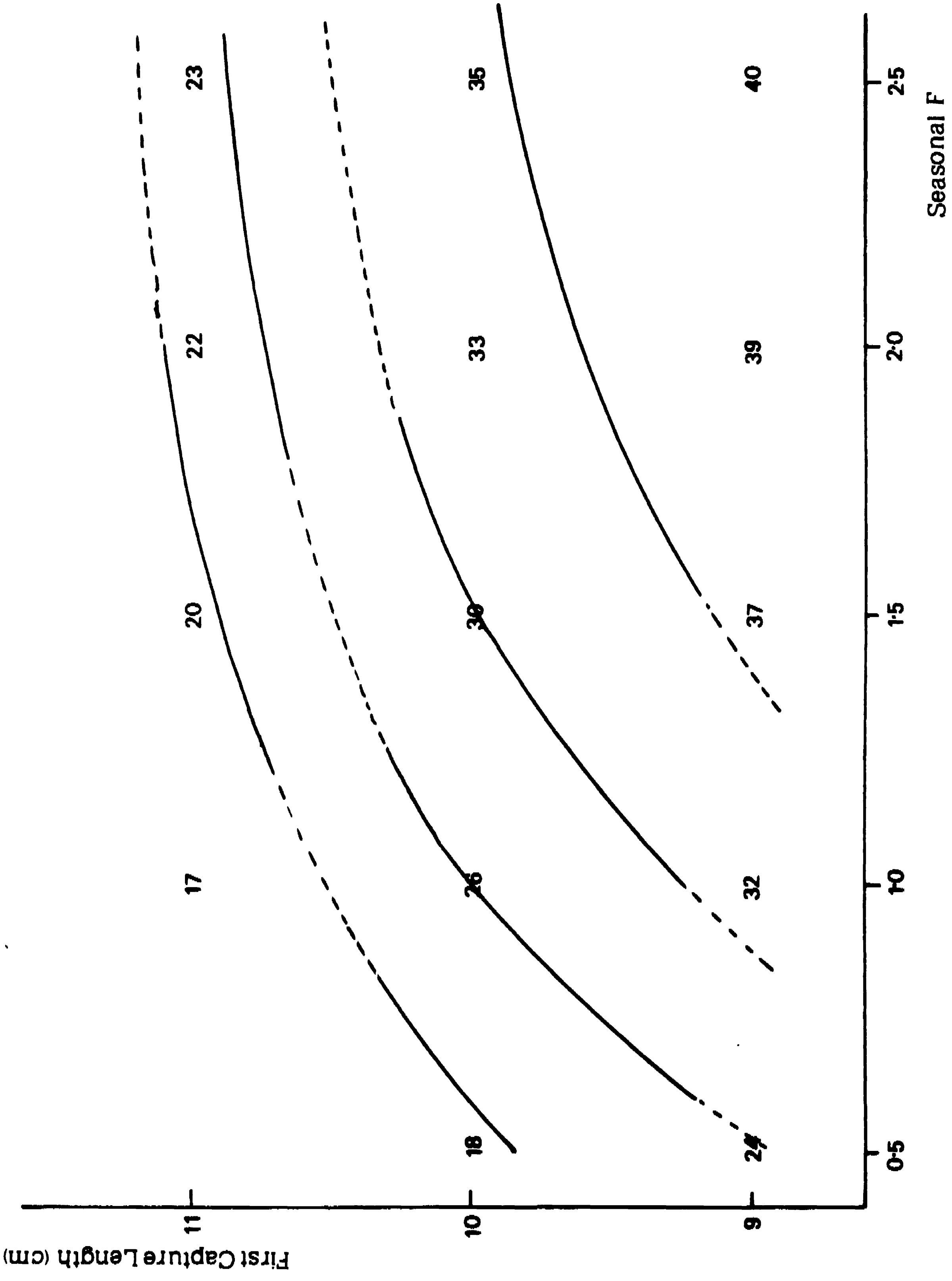


TABLE 1 Shell Lengths at each 'check' mark for each abalone

Shell Number	Shell lengths at each of the following 'check' marks										Total shell lengths (cm)
	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9	r_{10}	
1	3.1	6.2	7.8	8.9	9.8	11.1	11.6	12.3	12.6		13.0
2	5.9										6.7
3	5.7	7.1	8.0	9.3	9.9	10.8					11.1
4	5.2	7.1	8.0	9.1	9.8	10.4	10.8				12.2
5	5.1	6.4	7.8	8.8	9.4						9.9
6	5.2	6.6	7.9	8.9	9.9	10.4	10.9	11.3	11.4	11.6	11.8
7	4.7	6.6	7.6	8.6							9.2
8	5.1	6.6	8.1	9.2	10.2	10.9	11.5	11.8			12.0
9	4.9	6.9	7.9	8.8	9.2						9.5
10	4.9	7.0	8.1	8.8	9.4						9.6
11	4.9	6.1	7.1	7.9							8.5
12	5.1	6.0	6.9	8.1							9.0
13	5.4	6.5	7.2	7.9	9.5	10.1	10.5				10.6
14	5.4	6.8	8.1	8.9							9.7
15	6.0	7.1	8.1	8.5							8.7
16	5.2	6.5	7.6	8.5							9.1
17	5.3	6.8	8.2	9.2	9.8						10.4
18	6.0	6.8	7.5								8.4
19	4.6	6.1	7.9	9.0							9.5
20	6.1	7.5	*	9.1	9.8	10.5	10.7	10.9			11.2
21	5.1	6.1	7.8	9.2	9.7						10.3
22	5.4	7.0	8.4								9.0
23	5.7	6.7	7.7								8.6
24	5.4	6.3	7.2	8.4	9.0	9.6	10.2				10.7

* Refers to shell damage precluding the identification of 'check' marks.

....../2

TABLE 1 (Continued)

Shell Number	Shell lengths at each of the following 'check' marks										Total shell lengths (cm)
	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9	r_{10}	
25	5.4	6.3	8.0	8.6							8.6
26	5.2	6.0	7.6	9.4	10.2						10.7
27	5.5	6.5	7.4								8.3
28	4.7	5.9	8.4	9.1							9.5
29	4.9	6.5	8.2								9.2
30	5.3	6.9	8.0	8.8	9.7	10.2	11.2				11.0
31	5.1	6.3	8.0	9.7	10.3	10.6					10.8
32	5.1	6.3	7.5	8.9	9.5						10.2
33	4.6	6.4	7.2	8.8	9.7						10.1
34	5.5	7.2	8.1	8.8							9.4
35	5.6	6.7	8.0								9.1
36	4.8	6.3	7.3	7.8	8.4	9.1	9.8				10.3
37	*	5.8	7.0	8.7	9.1	9.6					9.9
38	4.8	6.7	7.7	8.9	9.3	10.2					10.5
39	*	6.6	7.9	9.3	10.1						10.3
40	5.0	6.6	7.7	8.5	9.3	10.0					10.1
41	*	*	*	8.6	9.2	9.8	10.1	10.3			10.5
42	*	*	*	9.8	*	10.7	*	11.2			11.8
Mean Length	5.2	6.6	7.8	8.8	9.6	10.3	10.7	11.3	12.0	11.6	
Standard deviation	0.4	0.4	0.4	0.5	0.4	0.5	0.6	0.7	0.8	-	
Number	38	39	38	35	24	16	10	6	2	1	

* Refers to shell damage precluding the identification of 'check' marks.

TABLE 2 **Estimated Shell Lengths for Given Ages**

Ages (yr)	Estimated shell lengths (cm)
0.5	4.2
1.0	6.6
1.5	8.3
2.0	9.4
2.5	10.2
3.0	10.7
4.0	11.3
5.0	11.6
6.0	11.8

TABLE 3 **Mean Weights and Mean Lengths for Abalone sampled on 30 March 1982**

Mean shell Lengths (cm)	Mean Weights (gm) Total	Edible flesh
81.1	65.2	28.3
98.9	127.7	57.4
110.2	183.3	75.0
122.2	260.7	110.7

TABLE 4 Estimated Total Weights and Edible Flesh Weights for given ages.

Ages (yr)	Estimated Weights (gm) Total	Estimated Weights (gm) Edible flesh
0.5	7.0	3.3
1.0	32.6	14.6
1.5	69.5	30.5
2.0	107.5	46.6
2.5	140.9	60.5
3.0	167.8	71.7
4.0	203.1	86.2
5.0	221.5	93.8
6.0	230.6	97.5

TABLE 5 Summary of Mean Gonad 'Surface' Areas Relevant to Abalone sampled on 29 and 30 March 1982.

Parameter Description	Sex	Gonad 'surface' areas in following shell length classes (cm)				Length classes combined
		50 - 79	80 - 99	100-119	120-139	
Mean surface areas	MALE	2.2	1.8	2.6	2.5	2.2
	FEMALE	2.2	2.6	3.7	4.9	3.2
Standard Deviation	MALE	1.7	1.2	2.5	1.1	1.9
	FEMALE	2.6	1.9	2.7	4.2	2.5
Number of Observations	MALE	14	15	18	4	51
	FEMALE	5	24	23	3	55

TABLE 6 Numbers and lengths of Abalone Caught During Each of the Survey Dives on 29 and 30 March 1982

Shell length classes(cm)	Numbers of abalone caught during each of the following eighteen dives																		Totals
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
50 - 54						1													1
55 - 59					1														1
60 - 64													1			2	1		4
65 - 69			1			1				1									3
70 - 74			2	2	3	1	2			1			1	1		2	2		17
75 - 79			1	2	2	1	1			1			1	1	2	3	3		18
80 - 84		3	4	3	5	1	1				1		3	2		6	4		33
85 - 89	1	2	6	1			2			1		1	1	1		5	5		26
90 - 94		3	6	2	3	1	3	2			9	3		1		6	4		43
95 - 99	2	4	3	1	1	1	3				7		1	2		6	6	2	39
100-104		5	3	6	3	1	1	4	2	2	10	6	3	3		5	6	3	63
105-109	1	1	3	4	2		4	2	2	2	2	6	1	1	1	3	2	9	46
110-114		1		3			2	3	3	2	1	3	4	3	4		2	7	38
115-119	2	1	3				2	6	2	1		3	1		1			4	26
120-124	5							5	2			1	1	1	5			7	27

..../2

Table 6 (Continued)

Shell length classes(cm)	Numbers of abalone caught during each of the following eighteen dives																		Totals
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
125 - 129				1		1	2	5					1					4	14
130 - 134	1						1	2					1					3	9
135 - 139																			
140 - 145								1											1
TOTALS	12	20	32	25	20	8	22	25	19	11	30	23	20	16	14	38	35	39	409
Water Depths (m)	9	8.5	6	8	12	6	6	9.5	10.5	9	9	6	8	7	7	7	7	9	

TABLE 7 Estimated Numbers Surviving per 'Recruit' on October 1, following the application of different fishing mortalities

Cohort Identities	Numbers surviving per'recruit' on October 1, after application of following fishing mortality coefficients						
	0.5	1.0	1.5	2.0	2.5	5.0	7.5
1+	912	875	839	805	772	627	509
2+	359	247	170	117	80	13	2
3+	141	69	34	17	8		
4+	56	19	7	2	1		
5+	22	5	1				
6+	9						
Totals	1499	1215	1051	941	861	640	511

APPENDIX 1

Worksheet: Showing example set of calculations for determining the yields per 1000 1+ cohort recruits entering the fishery on September 1 each year; the seasonal fishing mortality has been taken as 1.5 and the length at first capture as about nine centimetres. (* Edible flesh weights).

Time Period	Mortality coefficients F	Mortality coefficients M	Changes in Numbers	Catch Numbers	Mean Lengths (cm)	Mean Individual weights* (gm)	Catch weights* (kg)
Sept.	1.5	0.6	1000 - 839	115	9.15	42.6	4.90
Oct.	1.5	0.6	839 - 705	96	9.32	45.2	4.34
Nov.	1.5	0.6	705 - 592	81	9.48	47.8	3.87
Dec.	1.5	0.6	592 - 497	68	9.62	50.2	3.41
Jan.	1.5	0.6	497 - 417	57	9.76	52.6	3.00
Feb.	1.5	0.6	417 - 350	48	9.89	54.9	2.64
March	1.5	0.6	350 - 294	40	10.01	57.2	2.29
April	1.5	0.6	294 - 247	34	10.13	59.4	2.02
May-Aug.		0.6	247 - 202				
Sept.	1.5	0.6	202 - 170	23	10.60	69.0	1.59
Oct.	1.5	0.6	170 - 142	20	10.68	70.7	1.41
Nov.	1.5	0.6	142 - 119	16	10.76	72.4	1.16
Dec.	1.5	0.6	119 - 100	14	10.82	73.8	1.03
Jan.	1.5	0.6	100 - 84	11	10.89	75.4	0.83
Feb.	1.5	0.6	84 - 71	9	10.95	76.7	0.69
March	1.5	0.6	71 - 59	9	11.01	78.1	0.70
April	1.5	0.6	59 - 50	6	11.06	79.3	0.48
May-Aug.		0.6	50 - 41				
Sept.	1.5	0.6	41 - 34	5	11.29	84.8	0.42
Oct.	1.5	0.6	34 - 29	4	11.32	85.6	0.34

..../2

Appendix 1 (Continued)

Time Period	Mortality coefficients		Changes in numbers	Catch numbers	Mean Lengths	Mean Individual weights*	Catch weights*
	F	M			(cm)	(gm)	(kg)
Nov.	1.5	0.6	29 - 24	4	11.36	86.6	0.35
Dec.	1.5	0.6	24 - 20	3	11.39	87.3	0.26
Jan.	1.5	0.6	20 - 17	2	11.42	88.1	0.18
Feb.	1.5	0.6	17 - 14	2	11.45	88.8	0.18
March	1.5	0.6	14 - 12	1	11.48	89.6	0.09
April	1.5	0.6	12 - 10	1	11.50	90.1	0.09
May-Aug.		0.6	10 - 8				
Sept.	1.5	0.6	8 - 7	1	11.61	93.0	0.09
Oct.	1.5	0.6	7 - 6	1	11.63	93.5	0.09
Nov.	1.5	0.6	6 - 5		11.65	94.0	
Dec.	1.5	0.6	5 - 4		11.66	94.3	
Jan.	1.5	0.6	4 - 3	1	11.67	94.6	0.09
Feb.	1.5	0.6	3 - 3		11.69	95.1	
March	1.5	0.6	3 - 2	1	11.70	95.4	0.10
April	1.5	0.6	2 - 2		11.71	95.6	
Totals				673			36.64

APPENDIX 2

Suggestions Concerning a Possible Future Biological Research Programme

Catch and effort statistics should be collected in respect to at least the three landing sites of Marbat, Sadh and Hudbin. If full-time enumerators are available at these sites, then for each fishing day and landing, the names of each diver and quantities of their catches should be recorded.

If full-time enumerators are not available, then representative days will need to be selected relevant to each site, and the same records as mentioned above collected for each landing on those days. The number of representative days should initially not be less than five per month at each site, and be reviewed as data becomes available.

The collection of more detailed information concerning fishing effort, and information about fishing locations should be obtained from interviewing representative divers, for example, all divers landing on the chosen representative days. The information recorded for each interviewed diver should include his name, quantity of catch, fishing location and number of diving hours, all relevant to a particular landing.

The length compositions of the catches by the divers should be obtained by measuring the lengths of at least two thousand abalone per month for each of the three sites. The practice of divers to accumulate the discarded shells in mounds on the beaches adjacent to the landing sites may facilitate this work, however, if the length compositions for these are biassed, which might occur if they only relate to catches from the nearby grounds, special arrangements to gain access to shells may be necessary.

The lengths and weights (both total and edible flesh), sex and gonad cross section surface areas of at least fifty abalone should be determined for each landing site per month. These data will be necessary for identifying the length at weight relationships, length at first maturity, spawning season and sex ratio. In addition the shells from these abalone should be cleaned and stored, for subsequent examination in respect to possible growth checks, and the assigning of ages.

Diving surveys at both the beginning and end of the fishing season, similar although more comprehensive than that described earlier in the report, should be undertaken to provide information of abalone abundances. Standard diving times should be employed, and attempts made to relate these to the areas of seabed covered. The diving should be done at depths both deeper and shallower than those able to be reached by the divers. The maximum depths at which abalone are found, and the width of the onshore reefs should also be determined.

A comprehensive tagging programme should be undertaken, in order to obtain alternative data concerning the length at age relationship for abalone, as well as information concerning the possible movement of abalone from deeper to shallow water. At least one thousand abalone should be tagged at each of the beginning and end of the fishing season, and placed into depths both deeper and shallower than those able to be reached by the divers.

The minimum manpower requirement,is sufficient enumerators to undertake the collection of catch statistics at each of the landing sites; probably the equivalent of one and a half full time persons. In the event of also undertaking the remainder of the programme described, the minimum requirement for this would be one biologist and an assistant. The conduct of the diving surveys and tagging may require the use of consultants with diving experience, possibly these people are only available from outside Oman. The time duration for implementing the total programme should not be less than two years, and probably not less than three years.